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A Summary of Control Room Envelope Inleakage Measurements

P. L. Lagus, Ph.D., CIH
Lagus Applied Technology, Inc.
San Diego, California

With the publication of Draft Regulatory Guide 1114, Draft Regulatory Guide 1115, the Draft Generic Letter on Control Room Envelope Habitability, and NEI Document 99-03 on the habitability of the Control Room Envelope (CRE), the measurement of inleakage (both filtered and unfiltered) into the CRE has become an important factor in the evaluation of nuclear power plant control room habitability.

As of the date of this abstract (4/2/02) inleakage has been measured in twenty-three distinct Control Room Envelopes at twenty-one plants using tracer gas techniques based on ASTM Standard E 741. Measured values of inleakage range from zero through approximately 4300 CFM. In this paper, the existing tracer gas air inleakage data will be tabulated and discussed. The source of various types of measurement errors will be described along with techniques for minimizing these errors.

Measurement of inleakage for the purpose of habitability analysis requires that consideration be given to the effects of adjacent ventilation systems on the measured inleakage. We provide data which demonstrate that the operation of adjacent ventilation systems can have a marked effect on the measured inleakage-at least for a Recirculation CREVS.

Since few inleakage measurements have been repeated in a manner that allows rigorous statistical uncertainty analysis to be undertaken, the majority of the testing has relied on the use of confidence limits to provide a measure of the uncertainty in a particular inleakage value. Confidence limits are often much larger than true statistical uncertainties due to the inherent conservatism of the confidence interval approach. A small number of repeat test data exist and will be described. These data can provide a crude estimate of the ultimate precision attainable for measuring inleakage into the CRE with tracer gas methods.

1.0 Tracer Gas Ventilation Measurements

Tracer gases have been used to measure the air infiltration and ventilation characteristics of buildings for over 30 years. Tracer gas techniques are successfully used in other areas of ventilation engineering and industrial hygiene to provide accurate characterization of HVAC performance under actual operating conditions [1,2].

Within the nuclear power community, tracer gas techniques have been used since the early 1980's to measure airflow patterns, to investigate health and safety monitor locations, as well as to understand potential gaseous radioactive contaminant migration within selected buildings [3,4]. In the past few years tracer gas measurements designed to measure inleakage (either total or unfiltered) into a nuclear power plant control room have been accepted by the NRC and are often requested whenever questions arise regarding the performance or adequacy of nuclear power plant control room habitability systems.

In fact, Draft Regulatory Guide 1115 and the Draft Generic Letter on Control Room Envelope Habitability both explicitly suggest that tracer gas testing is an acceptable method to characterize Control Room Envelope inleakage. In these documents, the NRC has denoted tracer gas testing as Integrated Inleakage Testing since the test itself measures the overall inleakage into the CRE.

2.0 Measuring Building Air Flows Using Tracer Gases

There are three principal tracer gas techniques for quantifying air flow rates within a structure; namely, the tracer concentration decay method, the constant injection or concentration buildup/steady state method, and the constant concentration method. All three of these techniques are incorporated in the most recent revision of ASTM Standard E741 "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution"[5]. Several of these tracer techniques are used to measure induced air flow rates in buildings such as those created by a mechanical air handling system.

The tracer concentration decay method is a direct way of measuring the air flow rate extant within a test volume under ambient flow conditions by measuring the decay in tracer concentration as a function of time within the space being tested.

The constant injection or concentration buildup/steady state method is an indirect method; i.e., it measures the equilibrium tracer concentration within a ventilated area. This concentration can be related to the air flow rate if the tracer release rate is known.

The constant concentration method is also an indirect method. It measures the amount of tracer as a function of time required to maintain a constant concentration within a ventilated zone or zones. The quantity of tracer injected can be related to the air flow rate. At present this is primarily a research method since the equipment required is more complex than that required for either the concentration decay or the constant injection test.

To interpret data resulting from tracer gas methods, one employs a mass balance of the tracer gas released within the volume under test. Assuming that the tracer gas mixes thoroughly within the test volume, the mass balance equation is,

$$V\, dC(t)/dt = S(t) - q(t)C(t) \qquad (1)$$

where V is the test volume, C(t) is the tracer gas concentration (dimensionless), dC(t)/dt is the time derivative of concentration, q(t) is the volumetric airflow rate into (or out of) the test volume, S(t) is the volumetric tracer gas injection rate, and t is time.

The air exchange or infiltration rate, A is given by $A(t) = q(t)/V$ where A is in air changes per hour (h_{-1} or ACH). In the simplest case, the value of A represents the flow rate of "dilution air" entering the volume during the test interval. Note that this "dilution air" can be actual outside fresh air or, more generally, it can be air whose origin is not within the test volume.

Recall that the simplest tracer gas technique is the tracer concentration decay test. After an initial tracer injection into a test volume S(t) is zero, and assuming A is constant, the solution to equation (1) for concentration as a function of time is given by:

$$C = C0 \exp(-A.t) \qquad (2)$$

where C_0 is the concentration at time t=0.

This method requires only the measurement of relative tracer gas concentrations, as opposed to absolute concentrations, and the analysis required to determine A is straightforward. In use, equation (2) is often recast to the following form;

$$\ln C = 1n\ C0 - A.t \qquad (3)$$

In practice one obtains a series of concentration versus time points and then performs regression analysis on the logarithm of concentration versus time to find the best straight line fit to the form of the equation given by equation (3). The slope of this straight line is A, the air exchange rate. The technique is shown schematically in Figure 1.

It is possible to solve equation (1) assuming a constant tracer gas injection. For the constant injection technique S(t) = constant. If A is also assumed to be constant, a solution to equation (1) is,

$$C(t) = (S/L) + (C0 - S/L) \exp(-A.t) \qquad (4)$$

A schematic representation of this technique is provided in Figure 2.

As depicted in Figure 2, the tracer concentration initially increases with time but eventually reaches a plateau. After waiting a sufficient time (equal to approximately 3/A), the transient dies out and concentration equilibrium occurs. Equation (4) then becomes the simple constant injection equation,

$$C = S/L \qquad (5)$$

The results obtained with this technique are exact only when the system is in equilibrium, (i.e. concentration is not changing as a function of time). Otherwise, the results will be subject to errors, with the magnitude of these errors depending on the extent of the departure from equilibrium. Thus it is very important that all tracer concentration data used in the calculation of inleakage values are equilibrium values.

In an air inleakage testing program using the concentration buildup/steady state technique, the total air inflow rate into the CRE is measured using equation (5). A constant flow rate of tracer gas is injected into the supply side of the CRE ventilation system and, after waiting for concentration equilibrium to occur, a number of measurements of the resulting concentration at the most downstream (in terms of negative differential pressure) portion of the CRE system are obtained. Recasting equation (5) yields the following:

$$L_{tot} = S / C_{av} \qquad (6)$$

Where L_{tot} now represents the total air inflow into the CRE. L_{tot} is made up of two components, namely, the amount of makeup air, $L_{m/u}$ and the amount of unfiltered inleakage, L_{unfilt} .

C_{av} is the average concentration measured at the downstream point after concentration equilibrium has been obtained. In practice a number of concentration readings taken over a period of time are used to determine C_{av}.

Making use of these quantities, we can write an expression for the total air inflow to the CRE as;

$$L_{tot} = L_{m/u} + L_{unfilt} \qquad (7)$$

Rearranging equation (7) to put the known quantities on the same side of the equation results in;

$$L_{unfilt} = L_{tot} - L_{m/u} \qquad (8)$$

Since $L_{m/u}$ can be measured independently either by means of a Pitot tube or hot wire anemometer traverse or by using a tracer flow measurement technique, it is possible to calculate the total air inleakage into the CRE using equation (6). Often $L_{m/u}$ is measured using a tracer gas technique. ASTM Standard E-2029 provides useful guidance for performing tracer gas flow rate measurements. [6]

Note that inleakage past CRE boundaries, isolation dampers, air handling unit housings, and return ducts contributes to L_{tot}.

3.0 Air Inleakage Measurements

In Tables 1 and 2 we present air inleakage values for the Control Room Envelopes that have been measured using tracer gas techniques as of 4/2/02. The data have been separated into inleakage values for Pressurization CREVS and for Recirculation CREVS. For some of the plants shown in the tables, retrofitting and remediation activities were undertaken after initial tracer gas testing in order to reduce the inleakage values. The plants then re-tested upon completion of the remediation/retrofitting. The data in the column marked "As Left" were generated at this time. In general there were significant reductions in the measured inleakage values due to the remediation/retrofitting efforts.

Note that we have provided a separate column for unfiltered inleakage since at several of the plants that exhibited inleakage, the measured value represented either partially or totally filtered inleakage. For one train of plant A and both trains of plant I, all of the measured inleakage was filtered inleakage. Consequently a numeric value of "0" was entered into the unfiltered inleakage column for these plants. Filtered inleakage has a much smaller effect on the overall habitability analysis. As such it is important to be able to distinguish *filtered* from *unfiltered* inleakage.

Two of the plants exhibit entries marked "RETEST". In both cases these represent inleakage tests that were undertaken to document any potential increase of inleakage value (or equivalently potential degradation of the CRE boundary or CREVS integrity) after several years had elapsed. For plant L additional remediation work had been performed prior to retesting, while for plant S no remediation had been undertaken during the interim.

A major assumption in the use of ASTM Standard E741 is that in the zone being tested the tracer gas is well mixed. Achieving satisfactory mixing of the tracer gas within the Main Control Room (MCR) has not been a problem as experience in many nuclear power plants has shown that air flows into such well ventilated rooms are sufficient to mix tracer over the time interval that elapses prior to initiation of sampling.

For CRE's that encompass more than just the MCR, or for those MCR's that incorporate rooms that may not be as well ventilated as the MCR, mixing can be achieved by use of portable oscillating fans. By measuring the tracer concentration at spatially separated locations one can then document the degree of mixing that has been attained. Experience has shown that mixing to within +/- 10 % is easily achieved and that often mixing to within +/- 2 % is possible.

In Table 1, several values are listed as "ZERO". These are inleakage values that have been reported or measured as negative values of inleakage. As negative inleakage is an unphysical result, these values are listed as "ZERO". The most likely explanation for these negative values is that errors in the measurement of makeup flow rates resulted in a numeric value that is greater than the total leakage rate into the CRE. The fact that one finds negative inleakage values underscores the difficulty in measuring makeup flow rates for some CREVS.

When one is using a tracer gas measurement of makeup flow rate, experimental experience suggests that by paying particular attention to the issues of mixing and tracer gas injection, the difficulties may be overcome. As an example, in the data for plant L the "As Found" data for the 2 fan CREVS tests resulted in negative values for inleakage. By careful consideration of measurement uncertainties, it was possible to calculate a range of inleakage values. These are tabulated in the appropriate rows in the "As Found" column.

The difficulty in this particular measurement was found to lie in our inability to properly mix the tracer gas in the length of makeup duct provided. For the RETEST, a special injection manifold was fabricated, the injection location was moved, and auxiliary mixing fans were inserted into the makeup duct. This resulted in well-mixed tracer gas concentrations in the makeup duct with subsequent measurement of inleakage. These values are tabulated in the "As Left" column.

A second, although less likely, explanation for a measurement of negative inleakage is that somehow the sample location for total inleakage has been incorrectly chosen. For instance, a sample location that did not include all the potential dilution (i.e. all the potential inleakage) would result in a similar situation (i.e. negative inleakage) even if the makeup flow rate had been correctly measured.

We should note also that just because a negative inleakage value was calculated and was then reported as "ZERO" does not imply that the inleakage actually *is* zero. This can only be established by a more careful experiment in which makeup flow rates are measured correctly.

A major source of uncertainty in the data of Table 2 for Recirculation CREVS is incomplete knowledge of the volume of the CRE. In a measurement of inleakage for a Recirculation CREVS, the uncertainty in CRE volume is directly proportional to the uncertainty in the calculated inleakage. In all but plant R, the uncertainty in the CRE volume was taken as +/- 2 %. The volumetric uncertainty used in the calculation of inleakage for plant R is not known to this author.

We hasten to point out that in the majority of inleakage testing programs tabulated in this paper, companion tracer gas measurements were undertaken-usually contemporaneously-to assess the contribution of various components of the CREVS and the CRE to the overall measured inleakage. Such measurements allow a plant to rank components in terms of contribution to overall inleakage in order to assist in developing a cost effective retrofitting/remediation plan. These techniques are described in a companion paper presented at this conference. [7]

4.0 Influence of Adjacent Zones on Inleakage values.

Prior to undertaking inleakage testing, a plant needs to consider the effects of adjacent ventilation systems on the overall inleakage characteristics of the CREVS/CRE. Whether there is a significant effect on inleakage due to operation of adjoining ventilation systems has been the subject of considerable discussion. In fact, section 2.3 of Draft Regulatory Guide 1115 specifically addresses the need to consider these effects.

Fortuitously, a number of tests were undertaken with adjacent ventilation systems operating under a variety of conditions at one plant that isolates and recirculates upon a high rad or toxic gas event. The object was to investigate the effects of the operation of adjacent (non-CREVS) ventilation systems on the overall inleakage.

At this plant isolation occurred either on a safety injection (SI) signal or on a high rad signal inside the CRE. If isolation occurred due to an SI signal, a special Auxiliary

Building ventilation system operated. If isolation was due to a high rad signal inside the CRE, the Auxiliary Building ventilation system did not operate. Consequently the differential pressures extant between the various zones would be different for the two operating conditions.

During each tracer gas air inleakage test, differential pressure between the CRE and various surrounding rooms was measured. This was accomplished with the use of two sensitive digital barometers. Initially, both barometers were placed next to each other and the units were "zeroed" against each other. One unit (the mobile unit) was then moved to various locations and the pressure values noted at timed intervals. The indicated pressure values of the unit remaining in the CRE (the stationary unit) were also recorded at timed intervals. The mobile unit was then returned to the stationary unit and both readings were again noted. This allowed a correction to be made for drift between the responses of the two units. Differential pressures were then calculated between the various locations by differencing the drift corrected values of the two digital barometers. Thus all differential pressures were measured relative to the floor of the CRE.

Where appropriate, elevation corrections were made to the readings of either or both barometers to ensure that the appropriate differential pressure was obtained. Immediately prior to undertaking a differential pressure measurement test, the local pressure gradient was measured.

Both differential pressure and air inleakage data for six different ventilation lineups are summarized in Table 3. Locations A through Q correspond to adjacent rooms that surround the CRE. It should be noted that the measured inleakage varied from 198 to 349 CFM depending whether the A or B train was operating as well as on the operation (or non-operation) of adjacent ventilation systems. Note also that there was considerable variation of the differential pressures relative to the CRE depending on the exact operating lineup of the CREVS and adjacent ventilation systems.

5.0 Reproducibility of Inleakage Measurements.

Since performing an inleakage measurement can be a time consuming and relatively expensive undertaking for a utility, repeated inleakage measurements under the same operating conditions are not generally undertaken. Thus to obtain an estimate of the uncertainty of the measurement it is necessary to rely on confidence interval calculations such as ANSI/ASME PTC 19.1. [8]

Simply put, this approach attempts to combine systematic and random measurement uncertainties in a statistically valid manner. Essentially a confidence interval is a statistical estimate of the spread expected in a series of repeated measurements based on a single series of measurements. The confidence interval is usually given at some percentage of confidence-usually 95 %. Thus if we say the mean value of a measurement is K with a 95 % confidence interval of M, we imply that if we repeat the measurement 100 times, at least 95 times the measured value will lie between (K+M) and (K-M).

Confidence interval calculations, by their very nature, are conservative and rely on detailed knowledge of the experimental uncertainties of the experimental apparatus used to generate the data.

The confidence intervals calculated for the measured inleakage values provided in

Table 1 range from approximately 8 % to in excess of 100 % and average approximately 40 %. The confidence intervals for Recirculation CRE's shown in Table 2 are generally lower and average approximately 5 %. We should note that the uncertainty in the inleakage values determined for Pressurization CREVS will always be larger than for Recirculation CREVS since in the former we are attempting to measure the difference between two relatively large numbers that are of comparable magnitude.

Repetition of an inleakage measurement a number of times on the same CRE with the CREVS operated in an identical manner each time would allow conventional statistical analyses to be employed and could possibly lower the estimated uncertainty attendant to the buildup/steady state technique used to characterize inleakage into Pressurized CRE's.

In the course of testing, three plants provided the opportunity to repeat inleakage measurements under essentially identical operating conditions. Two of the plants incorporated a Pressurization CREVS while the other was configured as a Recirculation CREVS.

In Figure 5, we provide inleakage values measured approximately three weeks apart (for plant M) and 18 months apart (for plant H). Both of these plants utilize a Pressurization CREVS. The plot presents the measured mean value of inleakage along with the upper and lower 95 % confidence limits. The numeric value shown is the mean inleakage value. In both cases the mean values agree to better than
20 %.

In Figure 6, we provide inleakage values for two operating trains of a single plant that isolates and recirculates. This plant retested approximately two years later to investigate the effects of aging on the measured inleakage value. Note that the values differ by less than 20 %.

It should be emphasized that repeat testing provides a measure of the precision (or reproducibility) of the inleakage value. This precision is affected by not only the inherent reproducibility of the test method, but also of the ability of the CREVS and the CRE to be configured and operated in a similar (and preferably identical) manner during subsequent tests.

6.0 Conclusions

We have seen that approximately 1/4 of the nuclear power plants in the country have undertaken integrated tracer gas inleakage testing of their Control Room Envelopes. Tracer gas testing has become an accepted technique for the measurement of CRE inleakage.

While some plants initially measured inleakage values in excess of the values used in their GDC 19 habitability analyses, ultimately all plants in the tables but one were in compliance either by retrofitting and remediation efforts, recalculation of their habitability analysis using more up-to-date assumptions and techniques, or a combination of both. One plant is still in the process of demonstrating compliance with GDC19 limits.

We have examined a suite of data obtained at a plant that isolates and recirculates its CREVS. The data demonstrate that adjacent zones can dramatically affect the inleakage characteristics of the CRE. Unfortunately the author knows of no such data for a Pressurization CREVS.

While one might not expect such a large effect for those plants that utilize Pressurization CREVS, the data presented underscore the observation that adjoining ventilation systems can affect measured inleakage. In particular, those plants for which the differential pressures are only slightly positive may experience effects on inleakage similar to those presented in Table 3. Draft Regulatory Guide 1115 explicitly suggests consideration of the conditions under which maximum inleakage can occur. The data shown in Table 3 demonstrate the need for such consideration.

We have also seen that for a limited set of inleakage data encompassing both Pressurization and Recirculation CREVS the reproducibility of measured inleakage values is on the order of 20 % or less. A larger data set that demonstrated a similar degree of reproducibility would allow the industry to adopt a smaller value of uncertainty in the measurement of inleakage especially for Pressurization CREVS.

7.0 References

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[5] ASTM Standard E741-00, "Standard Test Method for Determining Air Change Rate in a Single Zone by means of a Tracer Dilution", ASTM, Philadelphia. PA, 2000

[6] ASTM Standard E2029-00, "Standard Test Method for Volumetric and Mass Flow Rate Measurement using Tracer Gas Dilution", ASTM, Philadelphia. PA, 2000

[7] Lagus, P.L., "Component Leakage Testing using Tracer Gas Techniques" submitted for publication in the Proceedings of the 27th NRC/DOE Air Cleaning and Treatment Conference, Nashville, TN, 2002.

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Table 1

Pressurization CREVS Inleakage Values (SCFM)

CRE	CREVS	As Found Inleakage	As Left Inleakage	Unfiltered Inleakage
A	2 VSF 9	27 +/- 24		0
A	VSF 9	75 +/- 25	30 +/- 4	30 +/- 4
B	U1	35 +/- 44		35 +/- 44
B	U2	"ZERO"		
C	RAD	"ZERO"		
D-X	A System	144 +/- 24		144 +/- 24
D-Y	A System	49 +/- 49		49 +/- 49
E	A System	45 +/- 26		45 +/- 26
F	A	"ZERO"		
F	B	"ZERO"		
G	A System	341 +/- 91	156 +/- 86	156 +/- 86
G	B System	4056	162 +/- 91	162 +/- 91
H	A System	38 +/- 13		8
H	B System	34 +/- 18		8
I	A	196 +/- 10		0
I	B	137 +/- 15		0
J	Main System	916 +/- 43	586 +/- 69	586 +/- 69
J	Backup System	1086 +/- 99	484 +/- 57	484 +/- 57
K	AVE	2902 +/- 281	855 +/- 316	855 +/- 316
K	BVE	1135 +/- 284	711 +/- 282	711 +/- 282
K	AVC	NM	302 +/- 134	302 +/- 134
K	BVC	392 +/- 143	392 +/- 169	392 +/- 169
L-X	1 Fan System	379 +/- 141	80 +/- 55	80 +/- 55
L-X	2 Fan System	0-126		0-126
L-Y	1 Fan System	260 +/- 120	73 +/- 25	73 +/- 25
L-Y	2 Fan System	0-238		0-238
L-X	RETEST 1 Fan System		0 +/- 18	
L-X	RETEST 2 Fan System		0 +/- 30	
L-Y	RETEST 1 Fan System		0 +/- 13	
L-Y	RETEST 2 Fan System		0 +/- 42	
M	A	0 +/- 52		
M	B	0 +/- 30		
N	A System	NM	222 +/- 55	222 +/- 55
N	B System	273 +/- 99	88 +/- 62	88 +/- 62
O	A System	233 +/- 129		233 +/- 129
O	B System	189 +/- 103		189 +/- 103
P	A System	76 +/- 24		76 +/- 24
P	B System	83 +/- 37		83 +/- 37

Q	A System	339 +/- 72	181 +/- 34	181 +/- 34
Q	B System	305 +/- 72	156 +/- 27	156 +/- 27

Table 2

Recirculation CREVS Inleakage Values (ACFM)

CRE	CREVS	As Found Inleakage[a]	As Left Inleakage[a]	Unfiltered Inleakage
B	Recirculation	267 +/- 10		267 +/- 10
E	Recirculation	142 +/- 6		142 +/- 6
I	Recirculation	312 +/- 12		312 +/- 12
J	Toxic Gas:Main AHU	1187 +/- 41		1187 +/- 41
J	Toxic Gas:Backup	1251 +/- 43		1251 +/- 43
R	Recirculation	4300	3000	3000
S	Toxic Gas	439 +/- 17		439 +/- 17
S	Hi Rad	442 +/- 20		442 +/- 20
S	RETEST Toxic Gas	501 +/- 15		501 +/- 15
S	RETEST Hi Rad	450 +/- 13		450 +/- 13
T	A System	119 +/- 7	79 +/- 5	79 +/- 5
T	B System	133 +/- 8	91 +/- 6	91 +/- 6
U	A System: Rad. Mon.	349 +/- 12	166 +/- 5	166 +/- 5
U	A System: SI	258 +/- 9	145 +/- 5	145 +/- 5

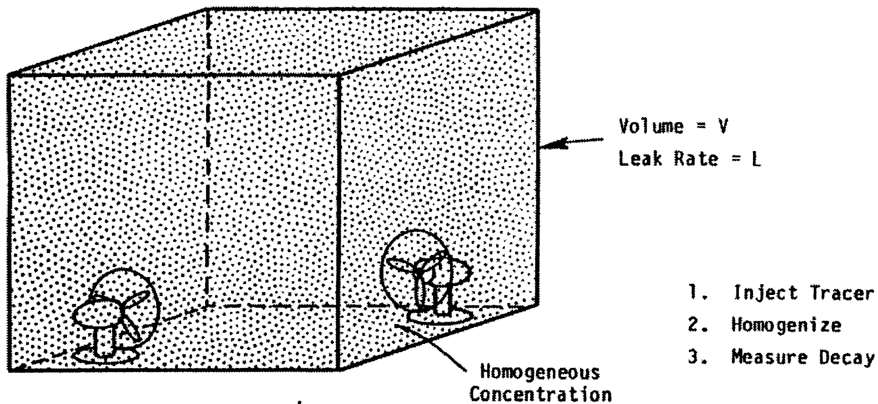
Table 3

Differential Pressure and Measured Inleakage

(Differential pressures are in. w.g.)

STATION	TEST I	TEST J	TEST K	TEST L	TEST M	TEST N
Control Room	0.00	0.00	0.00	0.00	0.00	0.00
A	-0.08	-0.02	-0.02	-0.01	-0.11	-0.13
B	-0.03	0.14	0.23	0.20	-0.07	-0.09
C	-0.19	0.04	0.13	0.03	-0.23	-0.25
D	-0.17	0.03	0.14	0.02	-0.24	-0.26
E	0.08	0.24	0.40	0.31	0.03	0.00
F	0.11	0.28	0.48	0.34	0.03	0.02
G	0.24	0.12	0.37	0.17	0.19	0.21
H	0.11	0.09	0.36	0.13	0.05	0.10
I	0.44	0.20	------	0.26	0.36	0.41
J	0.46	0.21	0.63	0.28	0.40	0.43
K	-0.03	0.22	0.65	0.30	-0.17	-0.15
L	0.48	0.21	0.69	0.28	0.42	0.43
M	0.50	0.23	0.78	0.30	0.47	0.45
N	0.49	0.24	0.82	0.28	0.47	0.46
O	0.51	0.43	0.68	0.35	0.45	0.07
P	0.20	0.11	1.13	0.38	0.13	0.53
Q	0.50	0.24	0.91	0.26	0.45	0.45
Control Room	0.00	0.00	0.00	0.00	0.00	0.00
Measured Inleakage (ACFM)	**291 +/- 10**	**220 +/- 7**	**258 +/- 9**	**198 +/- 7**	**263 +/- 9**	**349 +/- 12**

AIR LEAKAGE BY CONCENTRATION DECAY
ASTM E-741



$$C = C_o \exp\left(-\frac{L}{V} t\right)$$

Concentration	Time
C_0	0
C_1	10
C_2	20
C_3	30
•	•
•	•
•	•

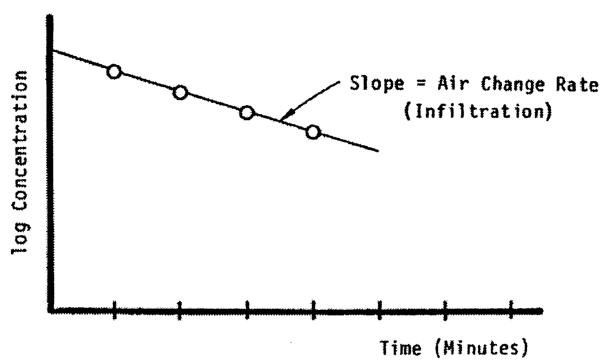


Figure 1. Tracer Concentration Decay Test

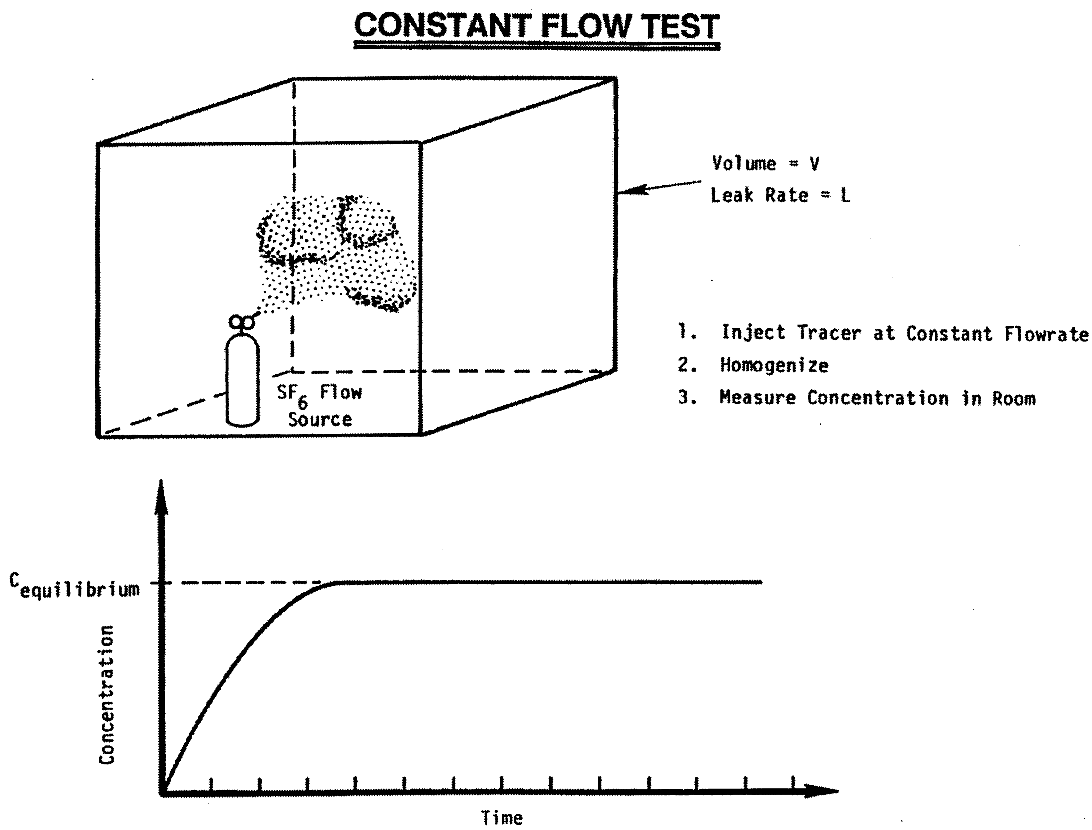


Figure 2. Concentration buildup/steady state test.

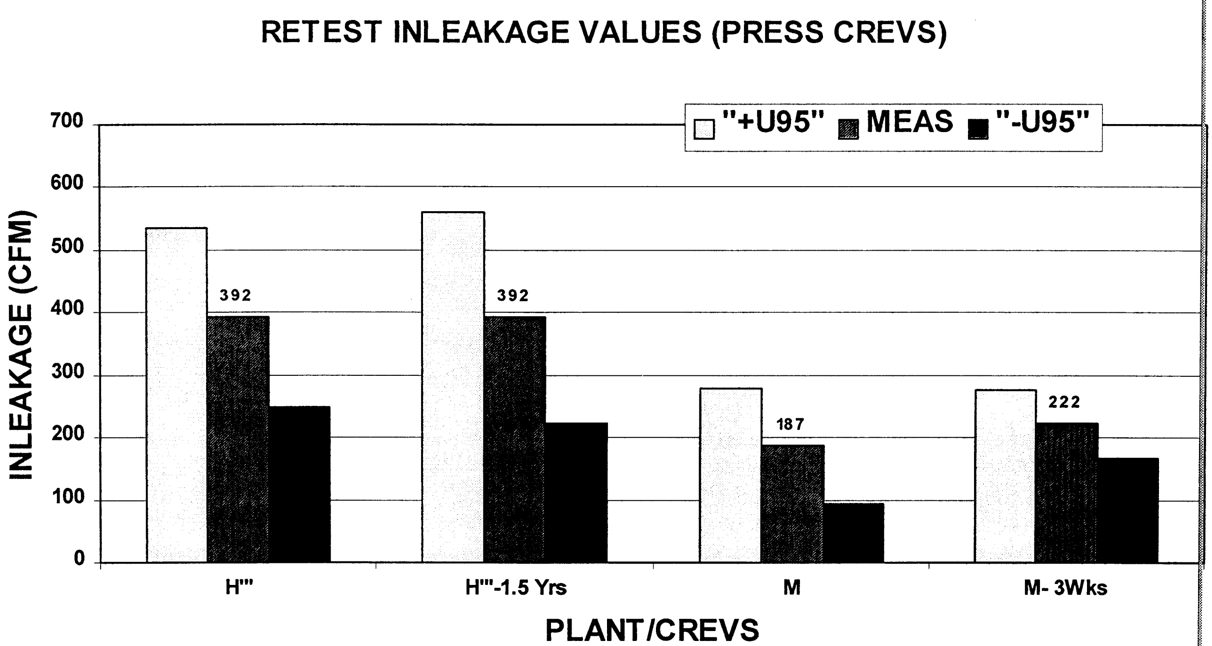


Figure 3. Repeat of Two Pressurization CREVS Inleakage Tests

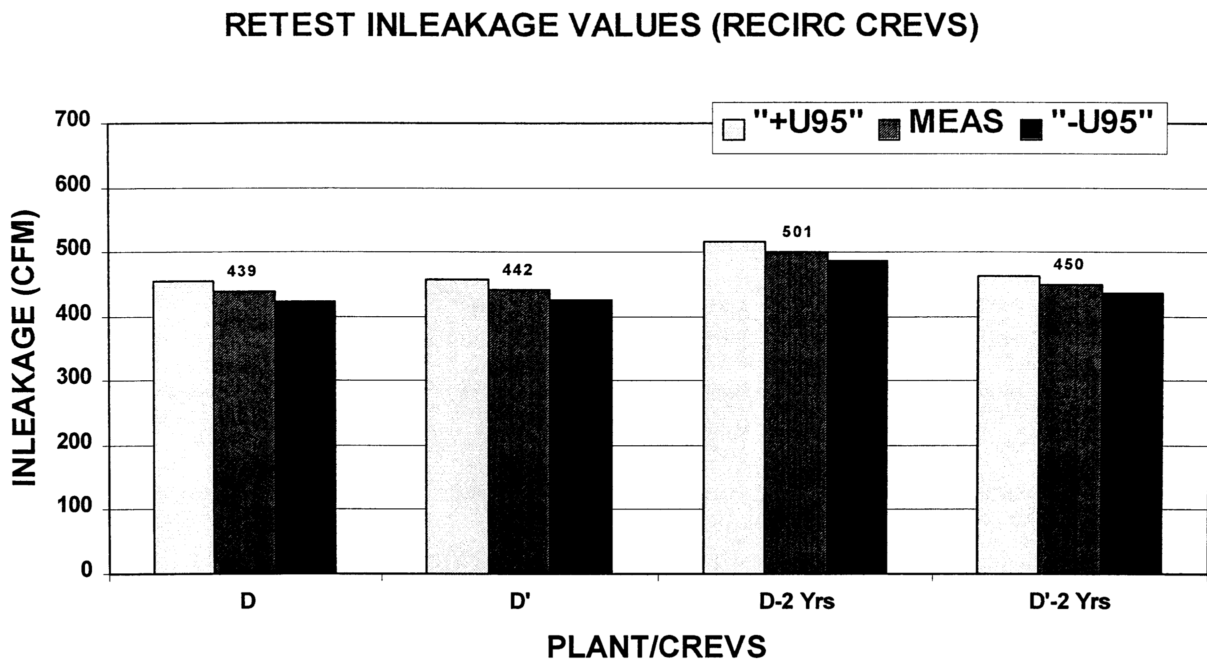


Figure 4. Repeat of Recirculation CREVS Inleakage Test